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Intelligent Techniques in Medical Volume Visualization

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Abstract

Visual representation of the interior body is a key element in medicine. There are many techniques for creating it; such as magnetic resonance imaging, computed tomography, and ultra-sound. The past few decades have witnessed an increasing number of new techniques being developed for practical clinical image display. Medical visualization brings profound changes to personal health programs and clinical healthcare delivery. It's seeks to reveal internal structures hidden by the skin and bones, as well as to diagnose and treat disease. This paper presents the recent intelligent techniques and algorithms used for medical data visualization. These techniques cover filtering, segmentation, classification and visualization. Additionally, this paper discusses state-of-the art toolkits and software supporting medical volume visualization.

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1. Introduction

Regarding physician diagnosis and therapy monitoring, medical imaging is one of the most important tools in the field and it also comes up handy in other fields like remote emergency assistance and surgical planning. Medical images can be obtained through different image modalities such as Ultrasound, X-ray, Magnetic Resonance Imaging (MRI), Computed Tomography (CT), Positron Emission Tomography (PET) or Single Photon Emission computed Tomography (SPET) [1]. The main problem with this large number of medical images lies in processing the enormous amount of obtained data (slice resolution with 16 bits/voxel precision can be provided by modern CT scanner). One approach is to render the data interactively using a specialized multi-processor hardware support. Since these devices are not cheap, they are not widely used in practice. Another alternative is to use volume visualization [2].

Volumetric medical image rendering is a method of extracting meaningful information from a three-dimensional (3D) dataset, allowing disease processes and anatomy to be better understood, both by radiologists as well as physicians and surgeons [3]. As for healthcare, the visualization impact is increasing rapidly in society. Medical imaging is fundamental for healthcare since the depiction of the body interior is crucial for the diagnosis of countless diseases and injuries [4]. For that purpose vast research and industry efforts have been put into the development of

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imaging devices scanning the patients and producing high-precision measurement data. Capturing the data is only the first step followed by the visualization step which is an essential link that presents this data to the physician as the basis for the diagnostic assessment.

The paper is organized as follows. Section 2 presents a brief explanation of volume visualization pipeline. Section 3 discusses the different Medical image techniques and the available databases for research. Section 4 represents the most commonly techniques for filtering medical images. Section 5 illustrates the available techniques used to segment medical image. Then, we elucidate the approaches used in classification in section 6. Sections 7 and 8 discuss both the medical image classification and volume image visualization techniques, respectively. Finally, section 9 presents the currently available toolkits used for medical image visualization.

2. Volume Visualization Pipeline

Following [5,6,7], the five processes used to preform volume visualization on medical image are shown in Figure 1. The first process is the acquisition of dataset, after that dataset filtered for enhancing the quality of the medical image, then segmentation step done to locate objects of interest for the medical image. After the possible selection of a sub-range of the voxels, the normal of the voxels are computed. For the last step before the actual rendering, the voxels are classified. Finally, the voxels are visualized.

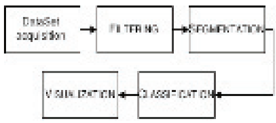


Figure 1: Volume visualization pipeline

The following sections highlight more details about each step of the above pipeline from the perspective of medical images.

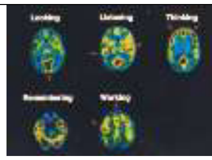
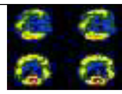
3. Medical Image Technologies

In 1895 Wilhelm Roentgen discovered a new form of radiation called X-ray, and that was the beginning. Since then medical image endure continuous innovation. Nowadays most of the images are digital. Medical imaging is the process of capture image by an acquisition system of the interior of a body for the physical attributes and clinical analysis. There are techniques used to display medical images; such as x-ray, CT, MRI, ultrasound, PET and SPET.

Table 1 shows the available techniques for acquisition the medical image with a comparison between them to illustrate the advantage and disadvantage for each on [8,9,10,11,12,13] which will help to determine the best techniques in the diagnosis. For example, CT images help doctors to get 3-D view of certain parts of the body, such as soft tissues, the pelvis, blood vessels, the lungs, the brain, the heart, abdomen and bones [14,15]. CT is the preferred method for diagnosing liver, lung and pancreatic cancers and evaluate bone injuries, presence, size and location of tumors and Cardiovascular disease [16,17,18]. On the other hand, MRI used for the diagnosing a number of conditions by showing the difference between normal and diseased soft tissues of the body [19,20,21]. PET often used to evaluate Neurological diseases such as Alzheimers and Multiple Sclerosis, Cancer, Effectiveness of treatments and Heart conditions [22]. Ultrasound preferred for Pregnancy, Abnormalities in the heart and blood vessels, Organs in the pelvis and abdomen and Symptoms of pain, swelling and infection [23,24,25,26], and last but not least, X-ray is used to show Broken bones, Cavities, Swallowed objects, Lungs, Blood Vessels and Breast (mammography) [27].

Table 1: Advantage and Disadvantage of Medical Image Technologies

Technology	Advantage	Disadvantage	Example

X-Ray Imaging	• Widely used and available • Experts available • High-spatial resolution • Excellent imaging of hard tissues (bones) .	• Radiation exposure • Difficulty in imaging soft-tissues • 2D projection hidden parts	
Computed Tomography (CT)	• 3D volume • High-spatial resolution .	• Increased radiation dose • Longer acquisition times • Shadows, difficulties imaging soft-tissues • Costly equipment .	
Magnetic Resonance Imaging (MRI)	• Good spatial resolution • True 3D acquisition • Excellent contrast for all tissue types • In vivo, non- invasive, no radiation	• Very expensive • Acquisition somewhat long (3D) • Poor temporal resolution(3D) • Patient discomfort, noise, claustrophoby • Strong magnetic field	
Ultrasound	• Low-cost • Proven technique. Experts available • Not invasive, no harmful effects • Good imaging of soft tissues • Easy dynamic acquisition	• Low-signal quality, speckle noise • Low penetration depth or low spatial resolution • Shadows from bones and other thick tissues • Mostly 2D • A much lower intensity range, resulting in lower contrasts compared to tomographic images • Unsharp boundary regions.	
Positron Emission Tomography (PET)	• Removes the problem of patient movement and simplifies the registration difficulties tremendously • PET is more sensitive than SPECT	• Expensive	
Single-Photon Emission Computed Tomography (SPECT)	• Provide true 3D information • Less expensive than PET scans	• Inefficient	

4. Medical Image Databases Available For Research

Medical image databases available for research are listed below with a brief description for each.

- **CTisus:** Nearly 181,000 images, plus protocols, case studies, learning modules, and multimedia .Images are listed under Teaching Files. [http://www. ctisus.com/].
- **MyPACS.net Reference Case Manager** : Over 12,000 file cases and 57,000 images with free online CME provided by the Departments of Radiology and Biomedical Informatics, Uniformed Services University. Optional free registration. [http://www. mypacs.net/].
- **EuroRad :** This database offers 5,000 peer-reviewed teaching cases from the European Society of Radiology. [http: //eurorad.org/].
- **Radiolopolis :** International member radiology community focusing on education, research and clinical practice; includes over 16,500 cases. Paid subscription is required. [http://www. radiolopolis.com].
- **Insight Journal:** Open Access publication on medical image processing and visualisation. [http://www. insight-journal. org/].
- **Open Access Series of Imaging Studies (OASIS) :** MRI data sets of the brain compiled and freely distributed by Washington University. [http://www. oasis- brains.org/].
- **Annotated Spine CT Database for Benchmarking of Vertebrae Localization and Identification** : The database consists of spine-focused CT scans of adult patients (older than 18) with varying types of pathologies. The database currently consists of 125 patients. For most patients, multiple scans from longitudinal examinations are available, resulting in overall 242 scans in the database. [http://research. microsoft.com/ en- us/projects/ spine/].
- **DICOM sample image sets :** This contains sample of DICOM image sets for different regions of the body. [http://www.osirix-viewer.com datasets/].

5. Filtering Techniques in Medical Image

Medical images are often deteriorated by noise as a various source of interference and other phenomena that affect the measurement processes in imaging and data acquisition system. The procedure and physiological system used in imaging diminish the contrast and the visibility of details. For example, planar projection unclear medicine image obtained using a gamma camera as well as single-photon emission computed tomography as well as SPECT image severely decadent by Poisson noise that is inherent in the photon emission and counting processes. Although mammograms (x-ray image of the breast) are not much affected by noise, they have limited contrast due to the nature and superimposition of the soft tissues of the breast which is compressed during the imaging procedure. The small differences that may exist between normal and abnormal tissues are confounded by noise and artifacts, often making direct analysis of the acquired images difficult. Image filtering is used to refine given image so that desired image features become easier to perceive for human visual and diagnosis [28,29]. For medical image there are three commonly types of image noise such as: Gaussian noise, Salt and pepper noise , and Speckle noise.

Table 2 represents the most common filtering techniques used to enhance medical images. It also shows the advantage and disadvantage of each technique. So for every noise type there is a preferred filtering technique. For example, Ilango and Marudhachalam [30] presented new hybrid filtering techniques for removal of Gaussian noise from medical image. The experiments have been conducted on brain tumor image and they found that the proposed hybird technique perform significantly better than other filtering techniques. Shinde and Dani [31] found that MRI, cancer, x-ray and brain images suffer from Gaussian noise they try to remove it by apply different techniques such as; Median filter, Adaptive filter and Average filter and they found that Adaptive filter works fine to remove the Gaussian noise. Zain et al. [32] enhance Bone Fracture Image by speckle noise reduction. Three different filtering techniques, median, average and Wiener in ultrasound images have been applied and they found that Wiener filtering techniques are the best techniques among the other three for reducing speckle noise. After enhancing the medical images, now is time for performing the segmentation process.

Table 2: Comparison of Medical Image Filtering Techniques

Filtering Technique	Method description	Advantages	Disadvantages
Low pass filtering	Removes the high term frequency	• Removing a small amount of high frequency noise. • Smooth an N dimensional signal by setting the filter factor to a low. • If you know the exact frequency of the noise you can explicitly set the cutoff frequency of the filter.	It is only a first-order filter it may not give you a step enough cutoff frequency for the application you need.
High pass filtering	High pass filter removes low frequencies	• Removing a small amount of low frequency noise. • You can either remove this noise from the N dimensional signal by setting the filter Factor to a low value. • If you know the exact frequency of the noise you can explicitly set the cutoff frequency of the filter.	First-order filter it may not give you a step enough cutoff frequency for the application you need.
Median Filtering	Median in statistic means literally the value in the middle.	• Its simple to understand. • The median filter preserves brightness differences resulting in minimal blurring of regional boundaries. • Preserves the positions of boundaries in an image making this method useful for visual examination and measurement. • Median computer algorithm can be customized.	• Less effective in removing Gaussian or random • Intensity noise. • Repeating will remove noise but at the expense of detail. • High computational cost (for sorting N pixels the temporal complexity is O(Nlog N) When the median filter must be carried out in real time the software implementation in general- purpose processors does not usually give good results. • Some median algorithms are not good for real time processing.

Histogram equalization	is a method for stretching the contrast by uniformly distributing the gray values.	It is a fairly straightforward technique and an invertible operator. So in theory if the histogram equalisation function is known then the original histogram can be recovered.	It may increase the contrast of background noise while decreasing the usable signal.
Mean Filter	Reducing the amount of intensity variation between one pixel and the next.	is a simple intuitive and easy to implement method of smoothing images.	• A single pixel with a very unrepresentative value can significantly affect the mean value of all the pixels in its neighbourhood. • When the filter neighborhood straddles an edge the filter will interpolate new values for pixels on the edge and so will blur that edge. This may be a problem if sharp edges are required in the output.

6. Medical Image Segmentation Techniques

Image segmentation is typically used to locate objects of interest as well as their boundaries in order to make the representation of a volumetric image stack more meaningful and easier for analysis. Traditionally, this process is manually done slice by slice, which requires expert knowledge to obtain accurate boundary information for the regions of interest. This editing process may take a lot of time as well. A number of computer-aided segmentation techniques have been developed for medical images. Segmentation is the method of labelling each voxel in a medical image dataset to state its anatomical structure [33,34,35].

Table 3 describes the techniques commonly used in segmentation along with a brief description of their advantages and disadvantages. To determine the best approach to solve the problem of image segmentation, Khan [36] performed a survey on the image segmentation techniques. He found that after the analysis of different techniques of image segmentation, it is observed that a hybrid solution for image segmentation which consists of two or more techniques is being the best approach. The next section discusses the techniques used for mapping images in the classification step of the previously mentioned pipeline.

Table 3: Medical Image Segmentation Techniques

Segmentation Technique	Method description	Advantages	Disadvantages
Thresholding method	Requires that the histogram of an image has a number of peaks each corresponds to a region.	It does not need prior information of the image. For a wide class of images satisfying the requirement this method works very well with low computation complexity.	• Does not work well for an image without any obvious peaks or with broad and flat valleys. • Does not consider the spatial details so cannot guarantee that the segmented regions are contiguous.
Edge detection approaches	Based on the detection of discontinuity normally tries to locate points with more or less abrupt changes in gray level. Usually classified into two categories:sequential and parallel.	Edge detecting technique is the way in which human perceives objects and works well for images having good contrast between regions.	• Does not work well with images in which the edges are ill-defined or there are too many edges. • It is not a trivial job to produce a closed curve or boundary. • Less immune to noise than other techniques e.g.Thresholding and clustering.
Region-based approaches	Group pixels into homogeneous regions. Including region growing region splitting region merging or their combination.	Straightforward for classification and easy for implementation, Work best when the region homogeneity criterion is easy to define. They are also more noise immune than edge detection approach.	• Are by nature sequential and quite expensive both in computational time and memory. • Region growing has inherent dependence on the selection of seed region and the order in which pixels and regions are examined. • The resulting segments by region splitting appear too square due to the splitting scheme.

Clustering Approach	Assumes that each region in the image forms a separate cluster in the feature space. Can be generally broken into two steps: •Categorize the points in the feature space into clusters. •Map the clusters back to the spatial domain to form separate regions.	Straightforward for classification and easy for implementation.	•How to determine the number of clusters(known as cluster validity) •Features are often image dependent and how to select features so as to obtain satisfactory segmentation results remains unclear . •Does not utilise spatial information.

7. Medical Image Classification Techniques

Mapping images into predefine classes is called image classification. It contains some basic principles as representation where extract visual feature of the image and generalization which is training and evaluating the classifier. The first and most vital component of any classification system is image representation [37]. It is categorized into two main approaches: (i) low level image representation, and (ii) patch based image representation.

The following is a list of the available approaches used in classification with the methods of each approach:

- **On the basis of characteristic used:**
  • Shape based. • Motion based.
- **On the basis of training sample used:**
  • Supervised Classification • Unsupervised Classification
- **On the basis of assumption of parameter on data:**
  • Parametric classifier • Non Parametric classifier
- **On the basis of pixel information used:**
  • Per pixel classifier • Subpixel classifiers • Perfield classifier • Object oriented classifiers
- **On the basis of number of outputs from each spatial element:**
  • Hard Classification (crisp classification) • Soft classification (fuzzy classification)
- **On the basis of spatial information:**
  •Spectral Classifiers •Spectral contextual classifiers
- **Multiple classifiers approach:**
  • Different classifiers have their own advantages and disadvantages. In this approach different classifiers are combined. Some of the methods for combining multiple classifiers are: Voting rules, Bayesian formalism, Evidential reasoning, and Neural networks.

Now it's time for the final step in the pipeline which is the visualization step. The next section discusses the techniques used for visualization.

8. Volumetric Medical Image Visualization Techniques

Visualization of medical images is used to determine the quantitative information about anatomic tissues properties and their related functions. Visualization is divided into two categories; 2D and 3D visualization. For 2D visualization, it displays multi-planar reformation (MPR) which includes three types; orthogonal, oblique, and curved planes. For 3D visualization, it displays two types of algorithms; surface renderings (SR) and volume renderings (VR) (both projection and surface types). These rendering techniques can be classified as direct and indirect rendering. Direct rendering includes direct volume rendering (DVR) and direct surface rendering (DSR), while indirect rendering includes indirect surface rendering (ISR).

DVR when compared to SR, its main advantage is that it keeps the interior information, and so provides more information about the spatial relationships of different structures. Generally DVR has high sensitivity specificity for diagnosis [38].

8.1. Direct Volume Rendering Techniques

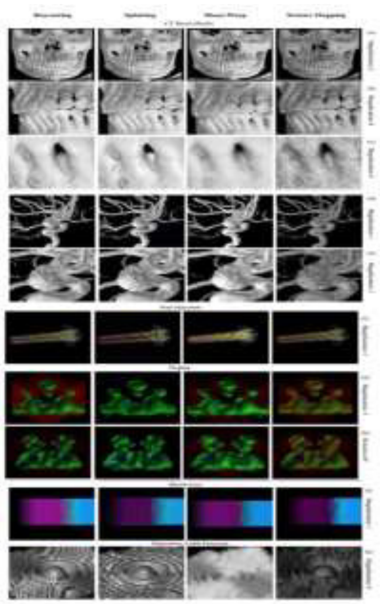
Direct volume rendering is a visualization technique that aims to get a 3D representation of the volume data directly. The data is considered to represent a semi-transparent light-emitting medium. It is divided into image-space DVR and object-space DVR. Object order methods use forward mapping to get 2D image of the original object from 3D volumetric data, an example is Ray Casting. On the other hand, Image order does this through backward mapping for example splatting, texture mapping and shell rendering.

The three main components in the direct volume rendering are, sampling, classification and composition. The effect of the optical properties of an image to be computed must incessantly integrated throughout the volume. But since the volume is represented by cells, or voxels, this needs to be done in a piecewise manner. Sampling deals with selecting piecewise steps taken through the volume, when classification computes color and opacity for each step, then compositing the final step where these steps blended together to form an image [38,39,40].

The techniques used in direct volume rendering are listed below with a brief description on each technique.

- **Software-Based Ray- casting:** Ray Casting is a natural image order technique. Since we have no surfaces in DVR, we have to carefully step through the volume. A ray is cast into the volume sampling the volume at certain intervals. The sampling intervals are usually equidistant, but they don't have to be. At each sampling location a sample is interpolated/reconstructed from the voxel grid.
- **Splatting Algorithms:** This technique was developed to improve the calculation speed of DVR at the expense of lower accuracy. This method accumulates data points by throwing kernels for each voxel to the drawing plane. The footprints on the drawing plane represent the visualization. The kernel shape and size is critical for the quality of the result.
- **Shear-Warp Algorithm:** It is a hybrid algorithm that attempts to combine the advantages of the image- or object- order based volume-rendering methods. The shear matrix transforms all the viewing rays so that they are parallel to the principal viewing axis in sheared object space allowing the volume and image to be traversed simultaneously.
- **Shell Rendering:** It is a software-based hybrid of surface and volume rendering which is based on a compact data structure referred to as a shell a set of nontransparent voxels near the extracted object boundary with a number of attributes associated with each related voxel for visualization.
- **Texture Mapping:** This is applied (mapped) to the surface of a shape or polygon. In 2D texture mapping (2DTM) the volume is decomposed into three stacks of perpendicularly object-aligned polygons. Three-dimensional texture map- ping(3DTM)uploads the volume to the graphics memory as a single 3D texture and a set of polygons perpendicular to the viewing direction is placed within the volume and textured with the image information by trilinear interpolation. Meiner et al. [41] compared the DVR techniques using different datasets of medical image. Fig. 2 shows representative still frames of the six datasets that rendered with the four volume rendering algorithms.

Figure 2: DVR techniques when applied in different datasets [41]



9. Open Source-Toolkits and Software for Medical visualization

In the last ten years the open source libraries and frameworks for medical research witnessed a huge evolution that they become essential for visualization, analysis, and diagnoses for medical image. This section discusses the most popular and successful open source libraries and software for medical image applications [42,43].

A. Visualization Toolkit (VTK)

VTK [44,45] is cross-platform, an open source library consider the main reason for the rapid development of medical imaging tools in a cost effective way, it's used for 3D computer graphics, image processing and visualization. VTK consists of a C++ class library and several interpreted interface layers including Tcl/Tk, Java, and Python. VTK able to handle different type of medical image data like CT, MRI, ultrasound data. VTK supports a wide variety of algorithms for image processing like coloring images based on a pre-specified color-map, producing and visualizing histograms, Gaussian smoothing, image re-slicing/resampling along an arbitrary axis from volumes, appending images to create a volume, and extracting and visualizing a region of interest, and for visualization algorithms including: scalar, vector, tensor, texture, and volumetric methods; and advanced modeling techniques such as: implicit modeling, polygon reduction, mesh smoothing, cutting, contouring, and Delaunay triangulation.

B. Insight Registration and Segmentation Toolkit (ITK)

ITK [46,47] is an open-source software toolkit widely used for the development of image segmentation and image registration programs. ITK was developed with funding from the National Library of Medicine (U.S.) as an open resource of algorithms for analyzing the images of the Visible Human Project. ITK is developed in C++. ITK is cross-platform, relying on the CMake build environment to manage the configuration process. ITK has also wrappers for java, Tcl, and python. ITK provide wide techniques for segmentation, registration, and image-filtering, but doesn't provide graphical interface or methods for visualizing data though, there is a process to integrate ITK with VTK, so ITK can take the benefit of the robustness of VTK for visualization. ITK support wide formats for image data such as, DICOM, PNG, VTK, BMP, JPEG, Siemens, Tiff, RAW, GE4x, and many others. ITK contains of algorithm for filters (thresholding, edge detection, gradient estimation, smoothing algorithms, and frequency transformations), registration (rigid registration, multimodal registration, multi-resolution registration, and deformable registration), and segmentation (region-growing, watersheds, level sets, and hybrid methods).

C. KWWidgets

KWWidgets [48, 49] is a free, cross platform and open source graphical interface toolkit, was mainly developed and used by Kitware to create open-source and commercial end- user applications similar to the ones that use VTK and ITK. KWWidgets provide graphical user interfaces and composite widgets to facilitate the rapid development of medical image analysis tools.

D. OsiriX

OsiriX [50, 51, 53] is an application for image processing dedicated to DICOM images produced by medical equipment for Mac users. It's also able to receive images transferred by DICOM communication protocol from any PACS or medical imaging modality. OsiriX specifically designed for navigation and visualization of multimodality along with: 2D, 3D, 4D and 5D Viewers. The 3D Viewer offers all modern rendering modes: Multiplanar reconstruction (MPR), Surface Rendering, Volume Rendering and Maximum Intensity Projection (MIP).

10. Discussion

This paper discusses the recent intelligent techniques and algorithms used for medical image visualization. These techniques cover filtering, segmentation, classification and visualization. The study was started with analysis of the various medical image technologies used for acquiring medical data sets. This was followed by discussing the advantage and disadvantage of the current approaches used to reduce the medical image noise. Subsequently for improving the analysis of an image, segmentation techniques were illustrated and compared, showing that the hybrid techniques are the best approach for medical image segmentation. Image classification approaches and their methods were presented. Moreover, this paper shed light on the visualization techniques and algorithms for direct volume rendering. Additionally the technical aspects of the current Toolkits and software that are used for visualization is presented and discussed. In this respect, the study includes Visualization Toolkit (VTK), Insight Registration and Segmentation Toolkit (ITK), KWWidgets, and OsiriX.

Our analysis reveals the following results :

1- CT technology is preferred for diagnosing liver, lung and pancreatic cancers and evaluate bone Injuries, presence, size and location of tumors and Cardiovascular disease.

2- MRI technology used for the diagnosing number of conditions by showing the difference between normal and diseased soft tissues of the body.
3- PET often used to evaluate Neurological diseases such as Alzheimers and Multiple Sclerosis, Cancer, Effectiveness of treatments and Heart conditions.
4- Ultrasound preferred for Pregnancy, Abnormalities in the heart and blood vessels, Organs in the pelvis and abdomen and Symptoms of pain, swelling and infection.
5- X-ray is used to show Broken bones, Cavities, Swallowed objects, Lungs, Blood Vessels and Breast (mammography).
6- MRI, cancer, x-ray and brain images suffer from Gaussian noise, adaptive filter techniques was the best techniques after applied different techniques.
7- Hybrid techniques are the best approach for medical image segmentation.

11. Conclusion and Future work

Medical visualization is important to understand the medical images. Inspired by this motivation, this paper addresses the technical problems and challenges of the intelligent techniques and algorithms used for processing medical images, namely: magnetic resonance imaging, computed tomography, and ultra-sound. This study covers the techniques of the following process filtering, segmentation, classification and visualization. In addition, a list of the current Toolkits that are currently used for visualization is presented and discussed. The study reveals hybrid techniques are the best approach for medical image segmentation is the best. In our future, work we are looking to develop mobile based intelligent system using direct volume rendering texture mapping technique with bones data sets.

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